Electron cooling demonstration with Recycler 8.9-GeV/c pbars

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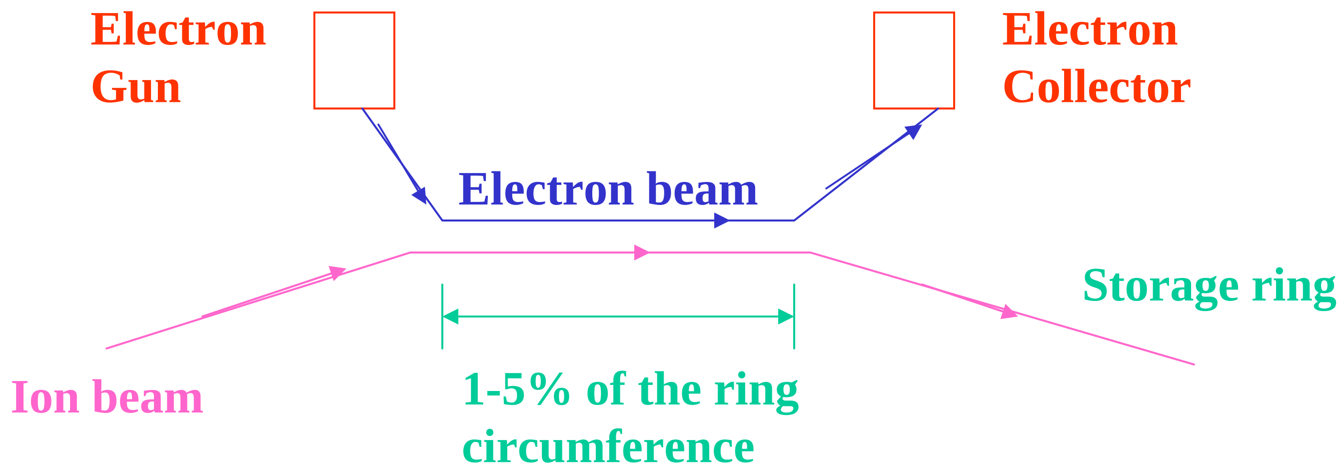
How does electron cooling work?

The velocity of the electrons is made equal to the average velocity of the ions.

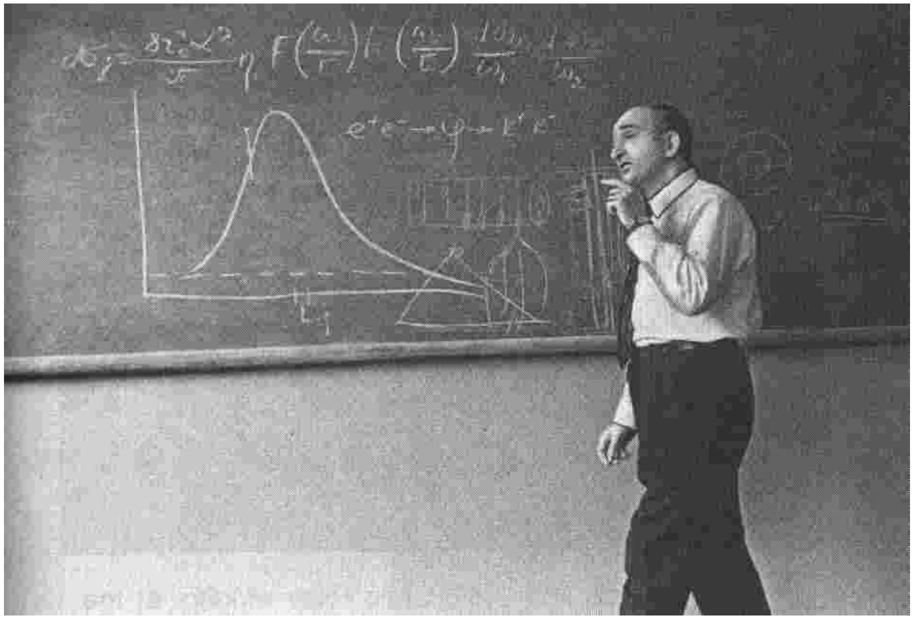
The ions undergo Coulomb scattering in the electron “gas” and lose energy, which is transferred from the ions to the co-streaming electrons until some thermal equilibrium is attained.



Electron cooling

- Was invented by G.I. Budker (INP, Novosibirsk) as a way to increase luminosity of p-p and p-pbar colliders.

- First publication at Symp. Intern. sur les anneaux de collisions á electrons et positrons, Saclay, 1966: “Status report of works on storage rings at Novosibirsk”



Laboratoire de
l'Accélérateur Linéaire
ORSAY

Institut National des
Sciences et Techniques Nucléaires
SACLAY

SYMPOSIUM INTERNATIONAL SUR LES ANNEAUX DE COLLISIONS

A ELECTRONS ET POSITRONS

Sous la présidence de

Monsieur Alain Peyrefitte

Ministre délégué chargé de la recherche scientifique
et des questions atomiques et spatiales

tenu à

l'Institut National des Sciences et Techniques Nucléaires, Saclay
26-30 Septembre 1966

Edité par

H. ZYNGIER
ORSAY

E. CREMIEU-ALCAN
SACLAY

STATUS REPORT OF WORKS ON STORAGE RINGS AT NOVOSIBIRSK

SHORT SUMMARY OF THE TALK GIVEN BY :

G.I. BUDKER

During the year elapsed since our last meeting in Frascati, the work in our Institute on colliding beams has been developed in three directions.

On electron-electron storage ring VEP-1 were performed high energy physics experiments : electron-electron elastic scattering [1] and double bremsstrahlung production for energies up to 2 x 160 MeV [2].

On electron-positron ring VEPP-2, we investigated the storing of electrons and positrons. After a first stage devoted to the understanding of numerous beam instabilities [3-7], experiments on electron-positron interaction at 2 x 380 MeV were undertaken [8]. Currents as high as 2 A of electrons and 20 mA of positrons were obtained with single beams, and 70 mA of electrons and 10 mA of positrons with interacting beams. At present time we already have detected some elastic scattering events at large angle and creations of π-meson pairs.

We have started working on the construction of our third set-up designed for proton-antiproton colliding beam experiments at energies up to 2 x 25 GeV. We are looking into the possibility of using this set-up also for electron-positron colliding beam experiments up to 2 x 6 GeV. It was decided that a second ring allowing proton-proton collisions will not be built since CERN undertook the construction of such a machine at a similar energy. The main tunnel for the machine is under completion. We are now experimenting different components of the system.

Fig. 1 shows the general lay-out of the set-up, with the accelerator-injector, the small and the big storage rings. The injector is an ironless proton synchrotron accelerating protons up to 500 MeV. Experiments on charge exchange injection into such a synchrotron have shown the possibility of obtaining currents near the space-charge limit (9).

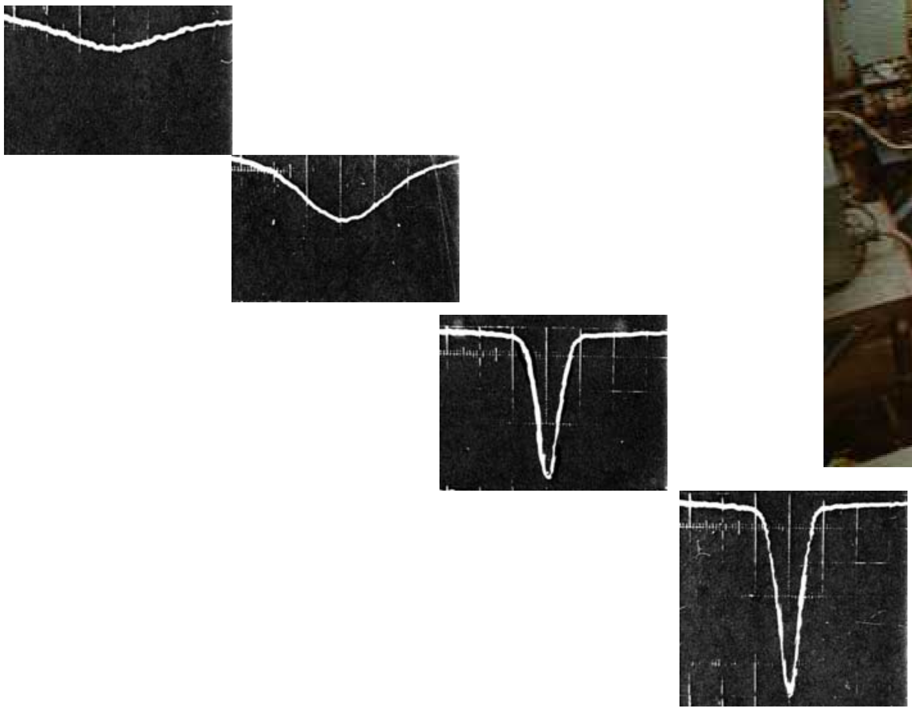
Lack of radiation damping for heavy particles somewhat complicates their accumulation. We are working out in our Institute a method of artificial damping through interaction between the proton beam and an electron beam. In discussions with prof. O'Neill, I found out that they also contemplated such a method several years ago, and named it "electron cooling".

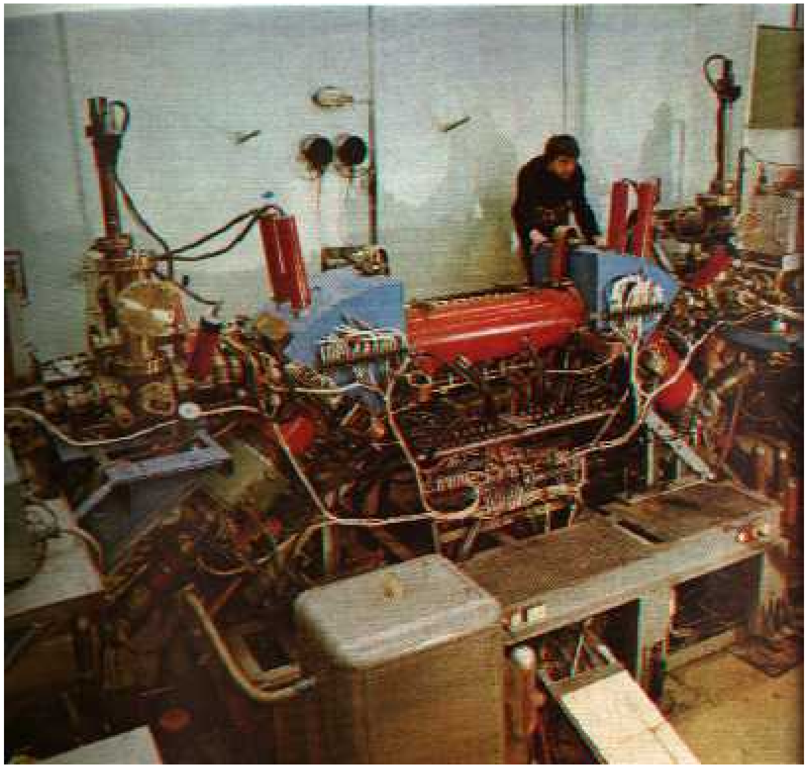
The stacking process in the proton-antiproton machine can be divided into several stages. The first one is the stacking of protons in the big storage ring. The length of the proton bunch in the synchrotron injector allows its capture in the large ring without loss of particles in one bucket of the 300th harmonic of the revolution frequency. After filling of the 300 buckets, the RF frequency is switched to the first harmonic. The particles are then accelerated to the maximum energy, and this reduces the bunch length approximately to the length of the small ring. Then the protons are ejected towards a special target to create antiprotons which are injected into the small ring.

According to our estimations, electron cooling will take about 100 seconds. Then, for the lifetime of one day, we can have about 1000 cycles of antiproton injection. After that, antiprotons will be reinjected into the big ring where colliding beam experiments will be performed.

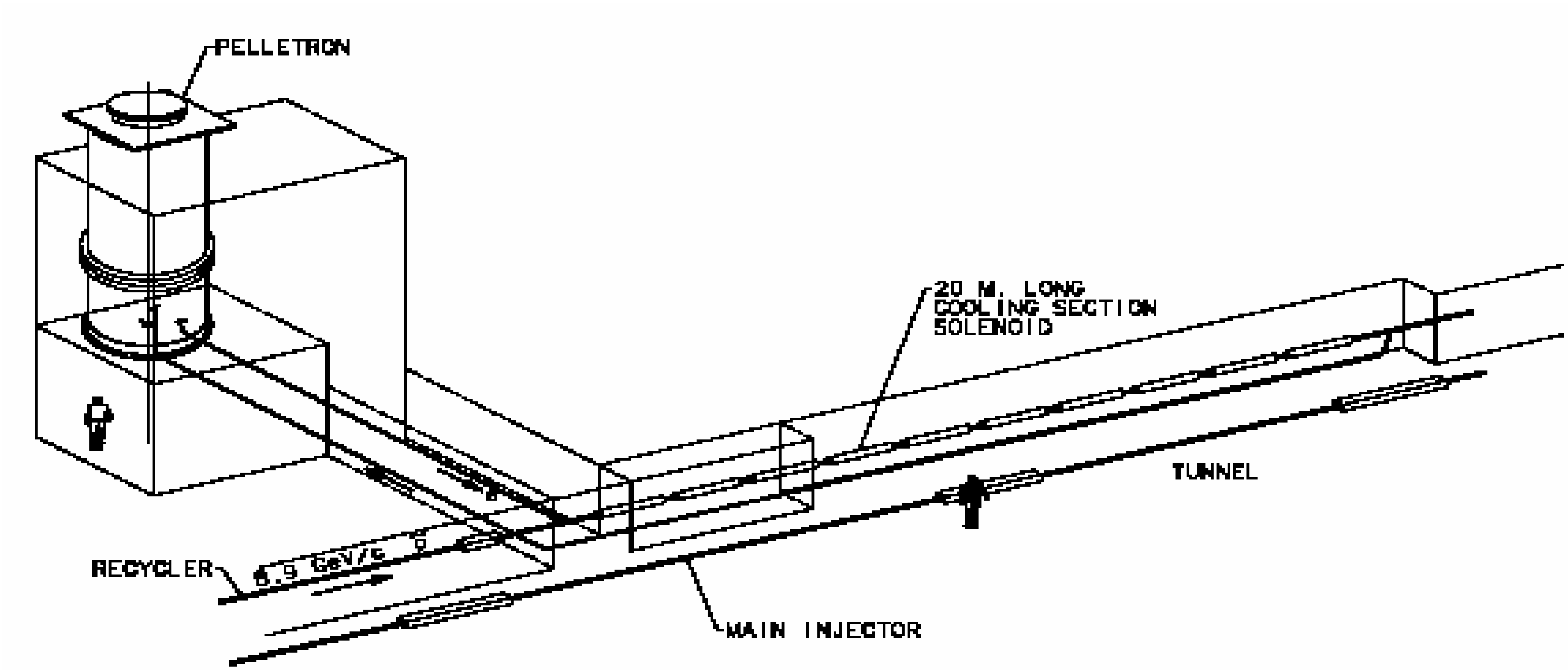
First Cooling Demonstration

- Electron cooling was first tested in 1974 with 68 MeV protons at NAP-M storage ring at INP(Novosibirsk).





Schematic Layout of the Fermilab Electron Cooling

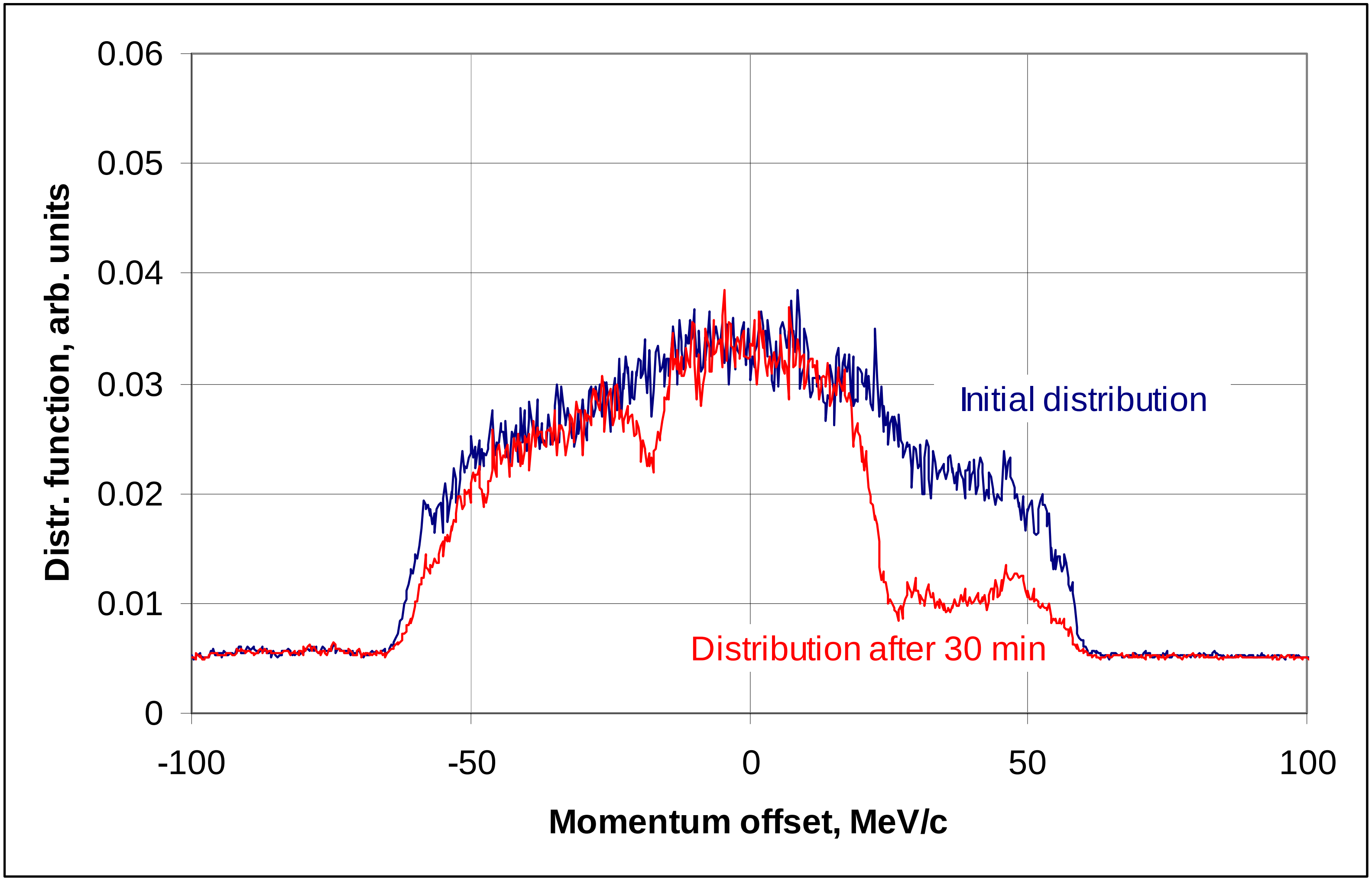


Electron beam parameters (design goals)

▪ Electron kinetic energy	4.34 MeV
▪ Absolute precision of energy	$\leq$ 0.3 %
▪ Energy ripple	$\leq 10^{-4}$
▪ Beam current	0.5 A DC
▪ Duty factor (averaged over 8 h)	95 %
▪ Electron angles in the cooling section (averaged over time, beam cross section, and cooling section length), rms	$\leq$ 0.2 mrad

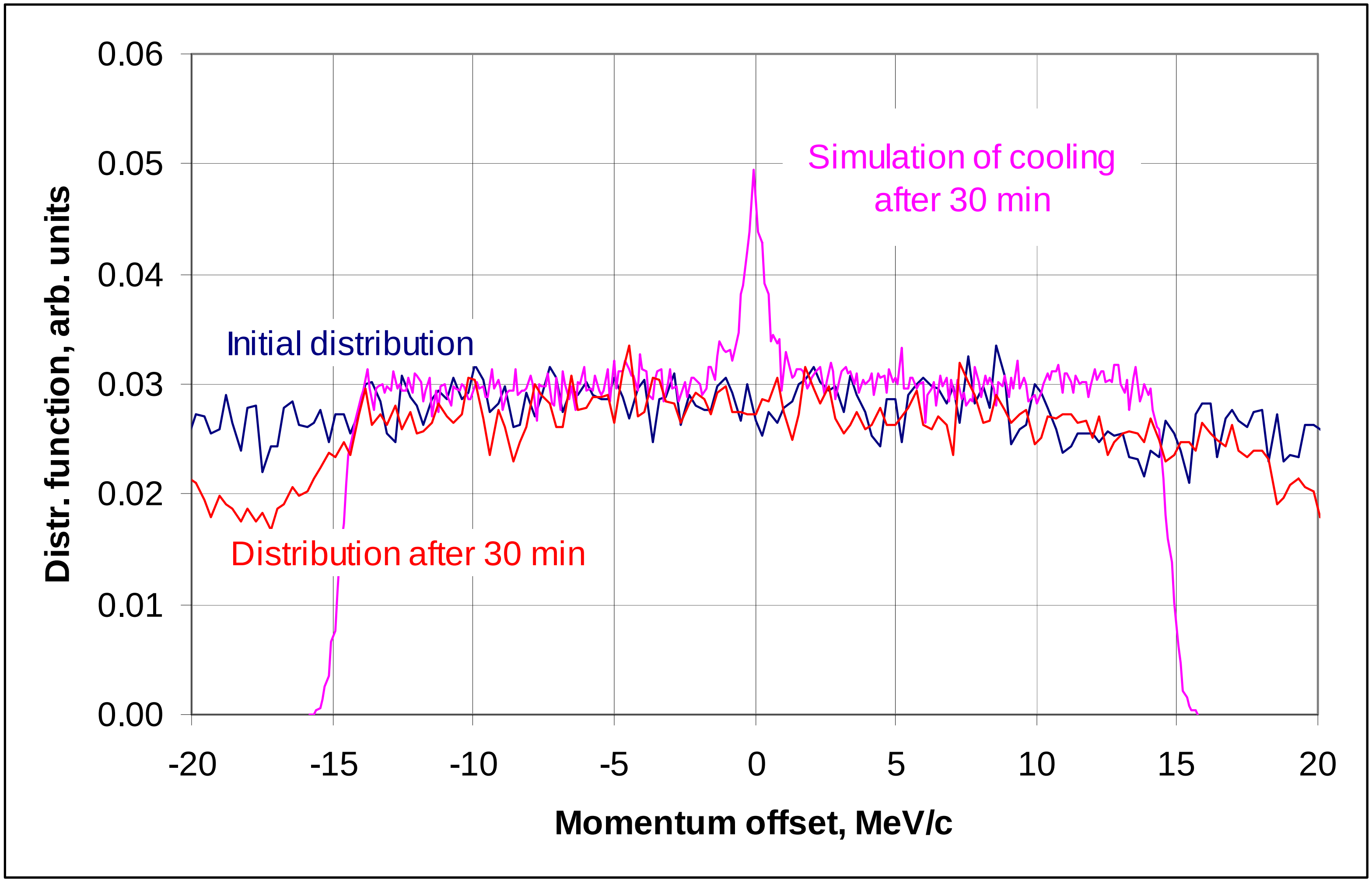
Recycler measured momentum distribution using Schottky

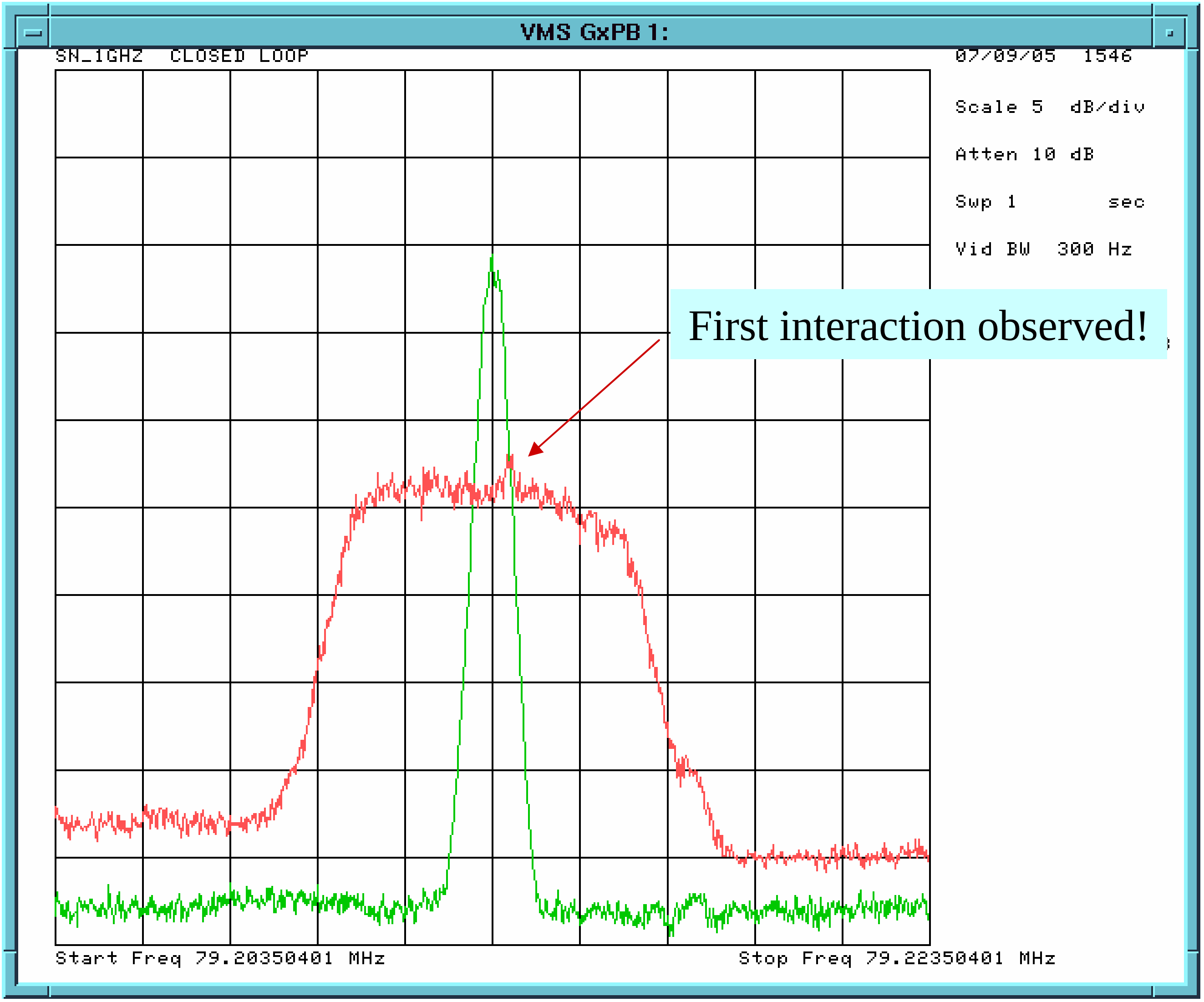
- 1.5e11 pbars, ε_n = 2 μm
- Momentum acceptance (flat central part): about 0.5% (+/- 22 MeV/c)



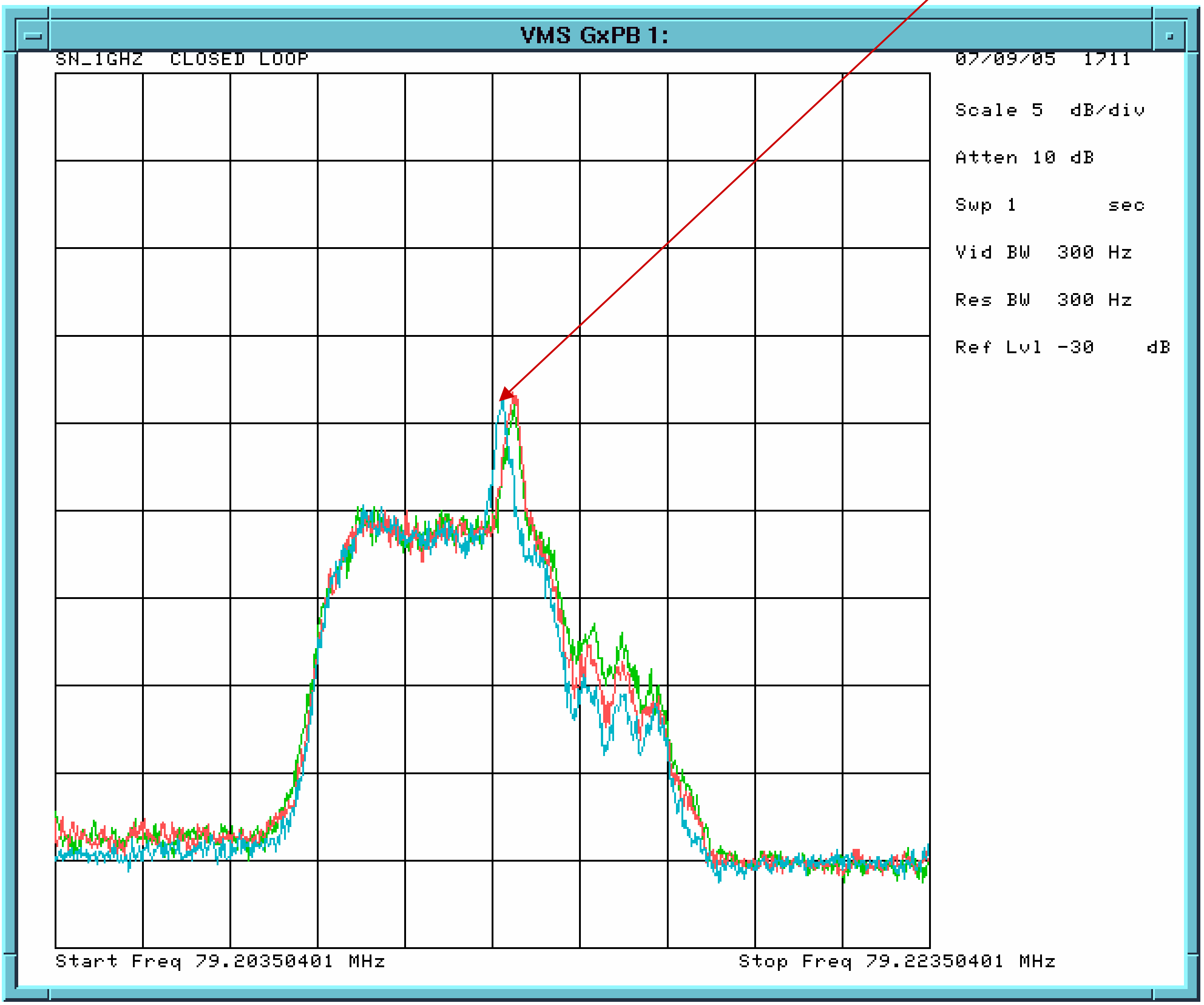
Simulation of cooling demonstration

- Without cooling -- the momentum distribution remains flat over 0.3% span for 30 minutes
- Coasting beam, IBS+ECOOL simulation, ε_n = 2 μm, Ie=0.1 A, rms angular spread = 0.5 mrad

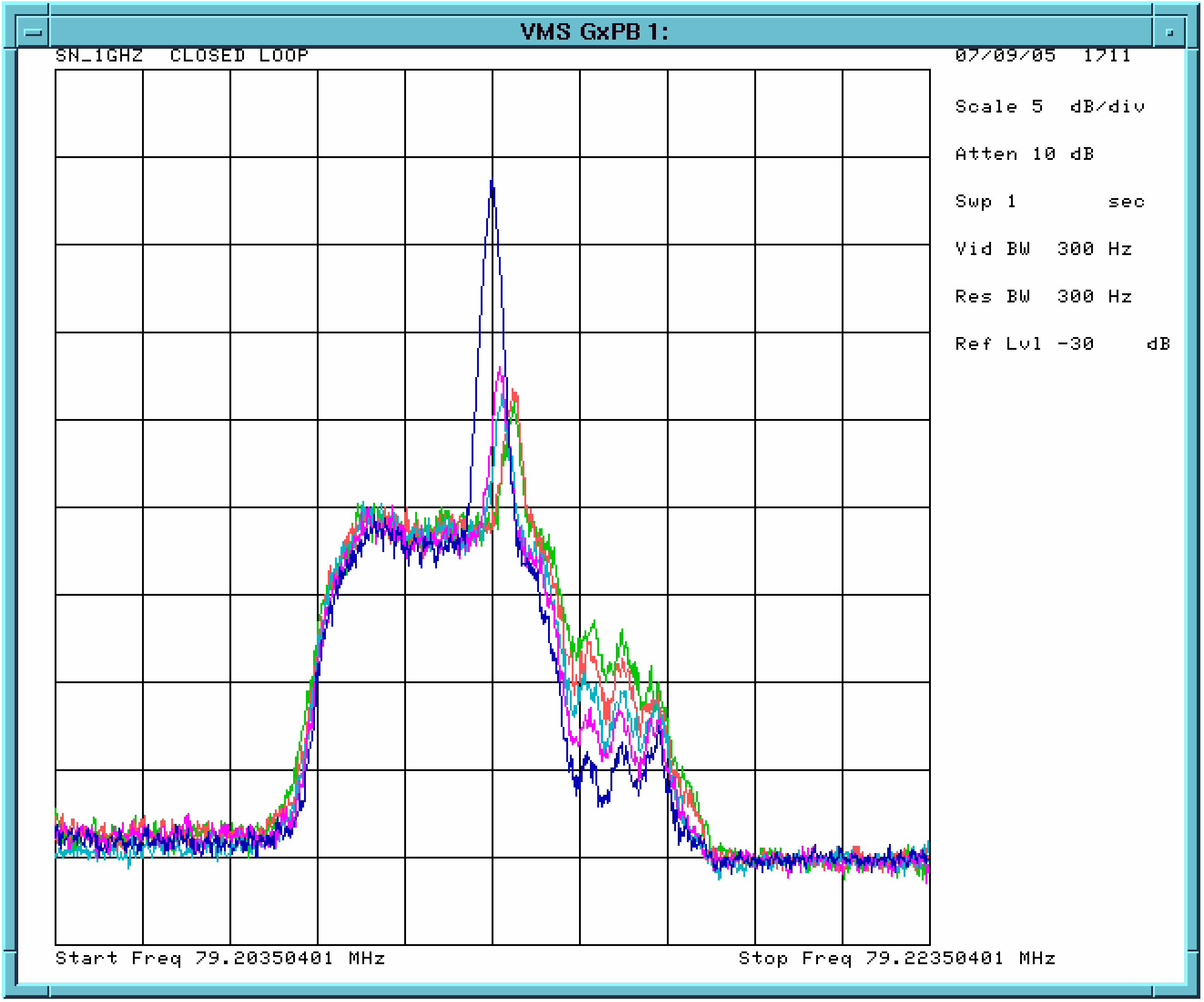



VMS GxPB 1:
SN_1GHZ CLOSED LOOP
07/09/05 1546
Scale 5 dB/div
Atten 10 dB
Swp 1 sec
Vid BW 300 Hz
First interaction observed!
Start Freq 79.20350401 MHz
Stop Freq 79.22350401 MHz

Electron energy shifted down by 2 keV.

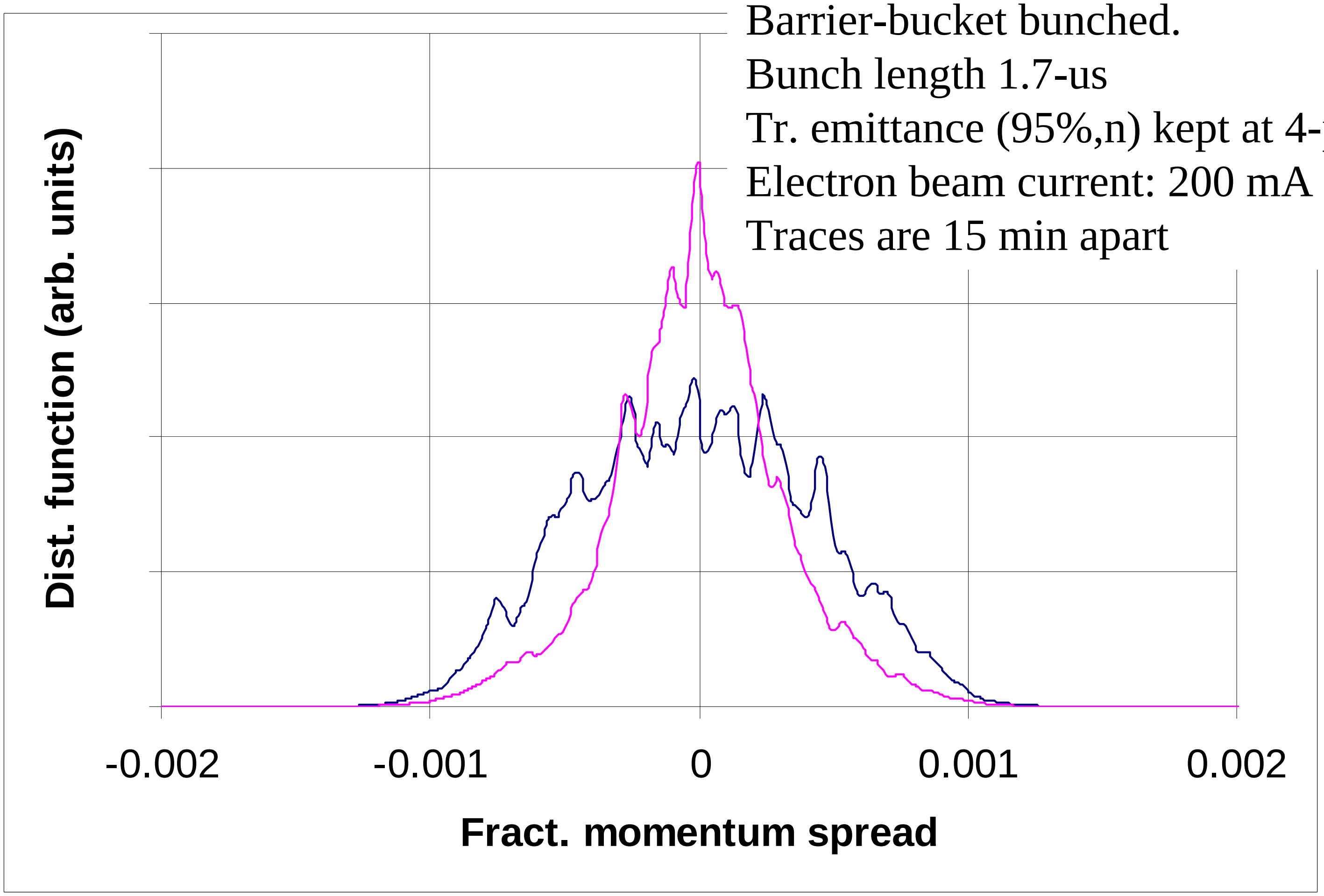


Energies aligned - we were within 3 kV!



First e-cooling demonstration - 07/15/05

Pbar beam: 63.5e10
Barrier-bucket bunched.
Bunch length 1.7-us
Tr. emittance (95%,n) kept at 4-pi mm-mrad
Electron beam current: 200 mA
Traces are 15 min apart



Milestones

	Plan	Actual
Commissioning begins	02/01/05	03/01/05
U-bend commissioned	03/14/05	04/15/05
Full beamline commissioned	04/04/05	05/04/05
A 0.5-A DC beam	07/08/05	
Cooling of antiprotons	09/08/05	07/15/05

Summary

- Demonstrated electron cooling ahead of schedule
- Fermilab now has a world-record electron cooling system
- Used electron cooling on two Tev shots – first time ever the ecool system used for a collider!
- Much work ahead to integrate the system into operations.